Bellcomm

date: November 22, 1971

to: Distribution

from: N. P. Patterson

B71 11027

subject: Time Limits on Astronaut Ultraviolet
Exposure - Case 340

ABSTRACT

The use of the Apollo Command Module quartz window (CM5) for lunar surface photography is re-examined. The factors which determine the flux of ultraviolet light reaching the astronaut through the unshaded window are discussed.

It is concluded that a total daily exposure of at least 58 minutes is safe. Extended exposures can be allowed near the terminator and where the field-of-view is not completely filled by the sunlit surface. If a daily dose larger than sunburn threshold is permitted at the astronaut's discretion, a further increase is available. The astronaut's eyes, however, should always be covered whenever it is possible for any ultraviolet light to enter the cabin.

A second Lexan window shade, with a hole in the center suitably fitted to the camera lens, is suggested as a means to obtain unlimited use of the window.

Bellcomm

955 L'Enfant Plaza North, S.W.
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date: November 22, 1971
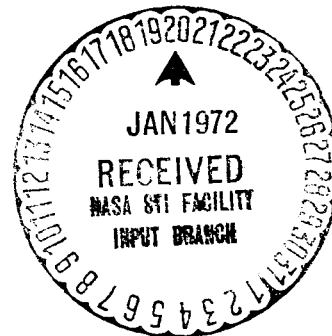
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MEMORANDUM FOR FILE

At the request of F. El-Baz, a review was conducted
of the potential ultraviolet burn hazard to an astronaut during
photographic activity at the command module quartz window (CM5).
This memorandum presents estimates of the length of time avail-
able for lunar surface photography through the uncovered window
and a suggestion on the type of window shield which would permit
unlimited use of the window.

In a letter to Dr. Karl G. Henize (see attachment)
the author presented exposure times in which a noticeable
ultraviolet burn could be acquired from the sun (direct rays),
and the earth and moon (reflected rays), under certain assumed
conditions. These times were used to limit the use of the
quartz window during Apollo 15.

The use of the window has been discussed with several
people, and based on the actual conditions, it now appears that
a significant increase in exposure at the window would be safe.
For lunar surface photography, the new value is about 58 minutes,
or 4.5 times the previous estimate. The factors allowing this
increase come about as follows:

1) Allowable Dose

    a) Skinburn - To acquire a barely noticeable sunburn,
the average person must receive an ultraviolet dose of roughly
2.5×10^5 ergs cm^{-2}. This corresponds to what one would re-
ceive during a 20 minute walk at lunchtime on a clear summer
day. A severe burn, resulting in blistering, would be caused
by a dose roughly 10 times greater than the above threshold
value and would be similar to the effects of spending 3 or 4
hours on the beach. These figures vary, and some individuals
are quite a bit more (or less) sensitive to sunburn than the
average. In the letter cited, the average threshold value of
2.5×10^5 ergs cm^{-2} was used as the basis for computing exposure
times.

Since most people regularly experience mild sun-
burn and develop a tan which reduces the sensitivity of their
skin to subsequent exposures, it would seem to be safe to
permit the astronaut to receive a daily dose perhaps three
times greater than the nominal threshold, increased to, possibly,
five times threshold at the end of the flight. It is assumed
that the astronaut would be permitted to use his own judgment
to reduce the daily dose if any noticeable effects were to
develop.

Graded exposure with a commercial sunlamp would be
a simple means of calibrating an individual astronaut before
flight, to establish these factors to the necessary accuracy.

b) <u>Eyeburn</u> The threshold dose sufficient to produce a
noticeable burn on the membrane of the eye is roughly 4×10^4
ergs cm^{-2}. The effects of such a burn are so distressing,
however, that no procedure should be permitted which might allow
the astronaut's eyes to receive even a small fraction of this
dose. It is recommended that protective wrap-around goggles be
worn whenever it is possible for ultraviolet light to enter
the cabin. If this is not practical, then the total exposure
accumulated over the flight must be kept well below the nominal
threshold dose, since it is unreasonable to test the astronauts
to determine their individual sensitivity.

2) <u>Subtended Angle of Reception</u>

a) During flight, the astronaut's hands and face do not
ordinarily approach the window, and are therefore not exposed to
a subtended angle of the full hemisphere field-of-view of the
lunar (or terrestial) surface which had been previously assumed.
Provided that skin surfaces remain more than ∿12" away from the
inner side of the quartz window, a factor of about 3 increase
would be allowable for all exposures to ultraviolet light re-
flected from the moon (or earth).

b) In addition, when a sizeable fraction, f, of the field-
of-view is not lighted (i.e., when the field-of-view includes
areas on the dark side of the terminator or the dark sky above
the limb) an exposure increase of a factor of $(1-f)^{-1}$ can also
be allowed for that photographic sequence.

For example, when the terminator divides the field-
of-view evenly, a factor of 2 increase is allowable on this
account. Together with the above factor of 3, a total in-
crease of a factor of 6 in exposure time, over the previous
estimate, would be allowable for exposure to ultraviolet re-
flected from the earth or moon.

3) Window Transmittance

        In the previous calculation, it was assumed that 90%
of all indident ultraviolet light was transmitted by the quartz
window. The actual window transmits roughly 70% of the
light incident perpendicular to its surface. Oblique rays
must travel a longer distance through the quartz panes and
will also be reflected more strongly at the surfaces. They
therefore would be attenuated somewhat more. The combined
effect of these considerations is that an increase of a
factor of 1.5 over my previous estimates is allowable for all
exposure times.

4) Lunar Reflectivity

        In the previous calculation, it was assumed that the
ultraviolet reflectivity of the lunar surface was 3%. Although
recent measurements indicate that the reflectivity decreases
to $\lesssim 1\%$ across the UV wavelength range of concern, skinburn
sensitivity and solar intensity are greatest near 3000Å, where
the reflectivity is probably not much less than 3% (Ref. 1).
I therefore do not believe an increase in exposure of a signi-
ficant factor is allowable on this account, although a slight
increase ($\sim 25\%$) may actually be safe.

5) Ultraviolet Intensity

        The ultraviolet brightness of the moon's (or earth's)
surface depends on the angles between the sun, the normal to
surface in the field-of-view, and the spacecraft. The brightness
seen from the window is greatest when looking directly down on
the subsolar point and it can be much dimmer (by a factor of
6-10) when looking down on lighted areas near the terminator.
The geometry of this effect is identical for visible and ultra-
violet light. The photometric function, Φ, which relates the
surface brightness, B, to the subsolar surface brightness, B_o,
is defined by the equation

$$\Phi = B/B_o.$$

It is currently used to determine the proper exposures for
visible light photography of the lunar surface. The variation
of Φ with orbital position of the CSM is similar in visible and
ultraviolet wavelengths (Ref. 1). It is programmed into the
camera settings in the flight plan and should therefore be
available for each point in the orbit where the quartz window
would be used. If these values are introduced, an increase
in ultraviolet exposure, over the previous estimates, of a factor
of Φ^{-1} is allowable for each photographic sequence.

Taking all of these factors into consideration, the allowable daily time limit for astronaut exposure to the uncovered quartz window, <u>for lunar surface photography</u>, is given by:

$$\Delta t_{new} = \Delta t_{old} \times (3\text{to}5) \times 3 \times 1.5$$

$$\text{or} \quad \Delta t_{new} = \Delta t_{old} \times (3\text{to}5) \times 4.5 = \sum_{\text{one day}} t_i \, \phi_i (1-f_i)$$

In the attached letter to Dr. Henize, 13 minutes was the estimated time required to receive a skinburn threshold dose from the moon under the conditions assumed. The author now feels that:

a) A daily exposure at least 4.5 times longer than this, or a minimum of 58 minutes, is definitely allowable.

b) At the astronauts' discretion, another factor of 3 to 5 is also probably permissible.

c) If values for the photometric function and the unlit fraction of the field-of-view are included, longer exposure intervals are allowable, especially for near-terminator photography.

d) These values should not be considered gospel, and any additional information available to persons familiar with the inflight use of the window should be taken into consideration in their application.

It should be pointed out that during the trans-earth portion of the flight, the sun is quite close to the earth in the field-of-view, and direct solar rays can enter the quartz window. In this case, the previous time estimate for skin burn threshold is 25 sec. and the increases discussed under items 2), 4) and 5) are not applicable.

In telephone discussions with Mr. Paul Ledoux of MSC it became apparent that no transparent material, thin enough to be flexible, would be useful as a protective "bag" over the window and camera. It would, however, be possible to cut a hole, say, 4" to 6" in diameter, in a second Lexan window shade. If a foam viton tube (or "doughnut") of similar diameter were attached to the periphery of this hole so that the lens barrel of the camera could be inserted snugly into the tube, yet still be pointed in any direction out the window, there would be no time

limit on the use of the window. A plug could block the tube
when it is not in use. Storage space for a second Lexan shade
is available in the CM. In case this suggestion, or something
similar, may be practical, the names of individuals who may be
able to expedite the modification are presented below:

Personnel associated with the use of the CSM Quartz Window

V. D. Brand, MSC/CB	8-(713)-483-2311
Aaron Cohen, MSC/PA	8-(713)-483-2126
Jerry Cragi, MSC/PD9	8-(713)-483-3441
Dr. Roger C. Fitch, MSC/ Neurophysiology Laboratory	8-(713)-483-4731
S. Nat Hardee, Jr., MSC/TM2	8-(713)-483-2666
Paul Ledoux, MSC/PD9, GE	8-(713)-483-3855
Ken Mattingly, MSC/CB	8-(713)-483-2421
Dr. Tobias Owens, State University of New York	9-(516)-246-6705
Hank Hartsfield, MSC/CB	8-(713)-483,2221
Elvin Pippert, MSC/CG5	8-(713)-483-4271
Stuart A. Roosa, MSC/CB	8-(713)-483-2411
Donald Segna, MSC/PD./PD	8-(713)-483-2457
P. D. Smith, MSC/ES12	8-(713)-483-2627
Chuck Willis, North-American Rockwell, Downey, California	9-(213)-922-6943
A. M. Worden, MSC/CB	8-(713)-483-2311

N. Paul Patterson

N. P. Patterson

1032-NPP-ajj

Attachments
 Reference
 Letter to Dr. Henize

REFERENCE

1. Ahmad, I. A. and Deutschman, W. A., "Ultraviolet Photometry of the Moon with the Celescope Experiment on the OAO-II," Paper presented to OAO Symposium, Amherst, Mass., August 1971.

October 2, 1970

Dr. Karl G. Henize
National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas 77058

Code: CB

Dear Dr. Henize:

Enclosed are my calculations of the ultraviolet exposures that may be received through the quartz window for the UV Photography experiment, S-177. Several people directly involved were helpful in providing details about the experiment and I am including their names for your information.

The results of my inquiry lead me to believe that there is cause for concern about injury to the eyes during the mission from exposure directly through the uncovered window but not from accumulation through the Lexan protective shade.

The Lexan shade will be 1/8" thick and is to remain over the window except during the 5-10 minutes required by each photographic sequence. It will provide adequate protection while in place.

The permissible eye exposure times are very short behind the uncovered window. The moon is a surprisingly strong source. During photographic operations I would recommend wearing protective eye covering and minimizing the area that is uncovered for the camera lens.

If there are any questions relating to these comments I would be glad to provide specific details.

Sincerely yours,

N. P. Patterson

APPENDIX

From the flux of incident ultraviolet radiation, F_λ, the transmission of the window, T_λ, and the relative action spectrum for burns, S_λ, the equivalent dose rate is given by:

$$\text{Dose Rate (equivalent)} = \sum_{\lambda_1}^{\lambda_2} F_\lambda T_\lambda S_\lambda \Delta\lambda$$

Where a threshold of exposure, Eo, is required to produce symptoms of injury caused by the radiation, the time required to reach this threshold is given by:

$$\Delta t = \text{Eo} \div \text{Dose Rate}$$

Table I contains the values of the flux from the sun, earth and moon, the relative activity of the various wavelengths and the transmission of quartz between 2000Å and 3150Å, the range effective in producing skin burn (erythema) and eye burn (photokeratitis).

TABLE I

λ (Å)	F_λ^1	E_λ^2	M_λ	S_λ^1	PK_λ^3	T_λ^1	T_λ^*
2000-2400 (mean)	3	3×10^{-2}	1×10^{-1}	1.0	.19	40-90%	8%
2400	6	1. "	2 "	.96	.33	90%	56%
2450	6	1. "	2 "	.91		"	
2500	6	1. "	2 "	.87	.20	"	
2550	10	1.2 "	3 "	80		"	
2600	13	1.5 "	4 "	.63	.37	"	
2650	20	1.8 "	6 "	.40		"	
2700	25	2.1 "	8 "	.12	1.0	"	
2750	22	3.0 "	7 "	.07		"	
2800	24	4.5 "	7 "	.06	.67	"	
2850	34	7.5 "	10 "	.13		"	
2900	52	12. "	15 "	.30	.57	"	
2950	63	19. "	19 "	.97		"	
3000	61	30. "	18 "	.70	.37		70%
3050	67	63. "	20 "	.30		"	
3100	76	190. "	23 "	.10	.20	"	
3150	82	300 "	25 "	.05		"	

F_λ = Solar flux[1] at 1 A.U. in ergs $cm^{-2}sec^{-1}Å^{-1}$.

E_λ = Flux received from earth[2] where it subtends $\gtrsim \Pi$ steradian field of view of windows in ergs $cm^{-2}sec^{-1}Å^{-1}$.

M_λ = Flux received from sunlight reflected off the moon where it subtends $\gtrsim \Pi$ steradian field of view of window. Constant 3% surface reflectance assumed.

S_λ = Relative Action Spectrum of ultraviolet for producing skin burn (erythema)[1]. Peak at 2967Å.

PK_λ = Relative Action Spectrum of ultraviolet for producing eye burns in primates (photokeratitis)[3]. Peak at 2700Å.

T_λ = Transmission[1] of 1cm thickness of various types of quartz (Suprasil, Infrasil, Ultrasil, Crystal, Vycor).

T_λ^* = Expected transmission of flight window, provided by S. N. Hardee, Jr. (3 panes, 3/4" thick each, Corning Type II).

The threshold for skin burn (erythema) is roughly 250,000 ergs cm^{-2} of 2967Å (or equivalent)[1]. The threshold for eye burn (photokeratitis) is about 40,000 ergs cm^{-2} of 2700Å (or equivalent)[3].

From table I it is found that the equivalent dose rates (erg $cm^{-2}sec^{-1}$) through a 90% transparent quartz window are:

	SUN	EARTH	MOON
Skin	1.0×10^4	58	312
Eye	1.1×10^4	60	322

The corresponding intervals required to reach threshold are:

	SUN	EARTH	MOON
Skin	25 sec	72 min	13 min
Eye	4 sec	11 min	2 min

These times would be somewhat longer through the actual flight window. For a Lexan window shade with 10^{-6} transmittance, the exposure time to sunlight could be increased to about 46 days before the threshold dose for photo-keratitis could be accumulated.

In the case of exposure to a series of sub-threshold doses, the skin develops greater tolerance against buring. The eye does not and may accumulate doses over a period of days with no symptoms until threshold is exceeded.

Some Personnel Associated with S-177

> P.I. Dr. Tobias Owens, State University of New York, (516) 246-6705.
> S. Nat Hardee, Jr. MSC/TM2, 8-713-483-2666 (rm 362 near your office)
> Dr. Roger C. Fitch, MSC/Neurophysiology Lab, 483-4731.
> Gary Coultas, MSC/PG, 483-2658.
> Randolph Carhart, General Electric Co., (413) 443-5338.
> Dr. Donald Pitts, Univ. of Houston, 748-6600 ext. 1831.

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REFERENCES

1. Ultraviolet Radiation (2nd edition, pages 108, 164, and 228), by L. R. Koller, Wiley (1965).

2. Atomic and Space Physics (page 510) by A. E. S. Green and P. J. Wyatt. Addison-Wesley (1965).

3. "A Comparative Study of the Effects of Ultraviolet Radiation on the Eye". SAM-TR-70-28 by D. G. Pitts, W. R. Bruce and T. J. Tredici, (July 1970).

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